The ALS as a Source of Intermediate-Energy X Rays.

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1. Introduction

The ALS was optimized to produce extremely high flux and brightness in the vacuum ultraviolet and soft x-ray region using undulator sources. It is also however an excellent source of intermediate energy x-rays, from 1 - 15 keV, and here the properties of various ALS sources, existing and proposed are benchmarked against the performance of the APS, NSLS and SSRL. Although the core program of the ALS will always be in the lower energy region, the complementarity of higher energy techniques and the potential to have a large capacity in this spectral range are powerful arguments for the full exploitation of the capability of the light source in the intermediate energy x-ray region.

The flux and brightness are widely used to characterize the quality of a light source and are presented here for the ALS in comparison to other DOE light sources. In the case of microfocus experiments in general the figure of merit is brightness. For experiments in which neither good angular collimation or a a small focus size are required, flux is the figure of merit. Several classes of experiment however have a figure of merit that is somewhere between flux and brightness and to evaluate the quality of the source the flux lying within the position-angle or phase space acceptance of the experiment has to be evaluated. One class of experiment that uses vertical brightness for example are those involving grazing incidence reflection or diffraction due to the small apparent sample size at small angles, and the high degree of angular collimation required. Another example is protein crystal diffraction where crystal sizes are often a few hundred microns and an angular collimation of a few milliradians is typical. In this case the figure of merit is closely related to the horizontal brightness. Care therefore has to be exercised in directly using flux and brightness to compare the characteristics of light sources.

In this note the ALS performance is benchmarked against existing light sources, and against an upgraded machine at SSRL. Finally the performance of the ALS with incremental improvements is compared to the APS.

2. Existing sources

In this section the performance of the ALS at its standard operating energy of 1.9 GeV is benchmarked against the existing APS, NSLS and SSRL machines. The graphics indicate for the most part the types of radiation source and so comments are only given here about specific devices and where clarification is needed. The accelerator parameters are given in Table 1 and the radiation source parameters in Table 2. Note that the accelerator parameters are not fixed for any machine, and constant incremental improvements are made to increase brightness, for example by a reduction of the vertical emittance. In Figs. 1 and 2 the flux and brightness of ALS bend and wiggler sources is compared to the APS bend, undulator A and wiggler sources. Figs 3 and 4 show the same comparison to the NSLS in this case for a bend source, in-vacuum undulator (IVUN), a permanent magnet wiggler and a superconducting wiggler. Figs. 5 and 6 show the comparison to SSRL radiation sources, for a bending magnet and for 15, 26, 30 and 54 pole wigglers. In summary, it can be concluded that in terms of flux, the APS wiggler is the highest output device with the ALS wiggler being competitive with all the others examined to at least 15 keV. The APS undulators offer extraordinary brightness at high energy with an advantage over the ALS wiggler of around 300 at 10 keV. The ALS and NSLS wigglers have a similar performance, and have more than an order of magnitude advantage over the brightest SSRL wiggler at 10 keV. A surprising result is that an ALS bending magnet has a higher brightness than the SSRL 54 pole wiggler up to 9.5 keV and higher than the 15 pole wiggler up to 14 keV.

3. Comparison to the SPEAR3 upgrade of SSRL

The comparison of the ALS to an upgraded SSRL with the SPEAR3 lattice is shown in Figs. 7 and 8 for flux and brightness respectively. In terms of flux the wiggler performances are similar, and the SPEAR3 bend now has a significantly better performance than the ALS for most of the energy range with an advantage of 4 at 10 keV. In terms of brightness, the ALS wiggler and SPEAR3 54 pole wiggler have similar performance over the whole energy range, and the bends become equivalent at 12.5 keV with the ALS having better performance at lower energy.

Storage rings and radiation sources can be incrementally improved over time, offering significant performance advantages. Fig. 9 and 10 show the flux and brightness of the ALS andthe SPEAR3 machine with additional radiation sources. These are by no means a complete set, and clearly with advancing undulator and wiggler technology as shown by the in-vacuum undulator pioneered at NSLS, substantial improvements can be made.

A 23 mm period small gap undulator has been studied at the ALS to cover the important 1 - 4 keV energy range. This has a similar flux and brightness performance to the APS undulator A proposed for SPEAR3 although the ALS device would have to use the 1st through 5th harmonics whereas the higher energy of SPEAR allows a longer period requiring only the 1st and 3rd harmonics have to be used. The ALS device will tune down to around 300 eV. The use of small gaps also allows the development of more optimum wigglers, and we have shown here a 50 mm period device with a 5 mm gap and 40 poles. This device would be operated with two sets of additional quadrupoles to decrease the vertical and horizontal beta values to 0.5 m and 3 m respectively. This together with the reduction in length and peak oscillation amplitude give an increase in brightness of around a factor of 8 at 10 keV.

A project was started in 1993 to investigate the possibility of replacing 3 out of the 36 bending magnets in the ALS lattice with high field magnets. This study matured into a construction project to build a prototype magnet and after 3 years of research and development, the LBNL superconducting magnet group recently produced a full scale prototype that has routinely demonstrated a peak field of 6.5 T and a field at the source points of 5 T. This is now a mature technology and involves relatively minor changes to the machine and would have minimal impact on the emittance. Each bend will give light into 2 bending magnet ports and each of these can be split into 2 beamlines. Three magnets therefore give us the potential to have 12 superconducting bending magnet beamlines. As shown in Figs. 9 and 10 these devices will have excellent performance to above 20 keV.

4. Comparison of future ALS sources to the APS

Finally it is useful to benchmark the subset of possible future devices that we can add to the ALS to those available now at the APS. This comparison is shown in Figs. 11 and 12. The 23 mm period ALS undulator fills in the energy range lower than that covered by APS undulator A, the small gap wiggler is competitive with the ALS wiggler in terms of brightness and the superconducting bend magnet offers very similar performance to an APS bend to above 20 keV. For those experiments requiring extremely high brightness in the x-ray range, for example phase contrast microscopy and coherent scattering, the APS undulators offer outstanding performance. However for a significant subset of experiments the limited brightness of ALS devices may well be sufficient. The prospect of superconducting bending magnets seems to offer an outstanding opportunity in that it will give us a significant number of exellent high energy x-ray sources for a low cost to complement the already excellent performance of our soft x-ray and VUV sources.

Table 1

Accelerator parameters

source	energy GeV	current mA	ε_h m.rads	ε_v m.rads	β_h ID, m	β_v ID, m	D_x ID	β_h bend, m	β_v bend, m	D_x bend	dE/E
ALS	1.9	400	6×10^{-9}	6×10^{-11}	11.2	4.2	0	0.85	1.46	0.094	8×10^{-4}
APS	7.0	100	5.7×10^{-9}	1.3×10^{-10}	14.2	10.1	0	1.8	18.4	0.085	1×10^{-3}
NSLS	2.58	500	9.4×10^{-8}	1×10^{-10}	1.1	0.41	0.15	1.6	10.5	0.34	8×10^{-4}
SSRL	3.0	100	1.3×10^{-7}	1.3×10^{-9}	16.5	1.9	1.05	2.8	24	0.56	7×10^{-4}
SPEAR3	3.0	200	1.8×10^{-8}	1.8×10^{-10}	14.5	7.0	0	1.0	7.0	0.1	9×10^{-4}

Table 2

Radiation Sources

source	bend (T)	undulator	wiggler	wiggler	wiggler	wiggler
ALS	1.27 & 5.0	λ_0=23mm N=40	λ_0=160mm N=37, B_0=2.1T			
APS	0.6	λ_0=33mm N=70	λ_0=85mm N=56, B_0=1.0T			
NSLS	1.22	λ_0=11mm N=31	λ_0=120mm N=27, B_0=1.0T	λ_0=174mm N=5, B_0=5T		
SSRL	0.77		λ_0=260mm N=15, B_0=1.9T	λ_0=175mm N=26, B_0=2.0T	λ_0=129mm N=30, B_0=1.5T	λ_0=70mm N=54, B_0=1.0T
SPEAR3	1.19	λ_0=33mm N=70	λ_0=260mm N=15, B_0=1.9T	λ_0=175mm N=26, B_0=2.0T	λ_0=129mm N=30, B_0=1.5T	λ_0=70mm N=54, B_0=1.0T

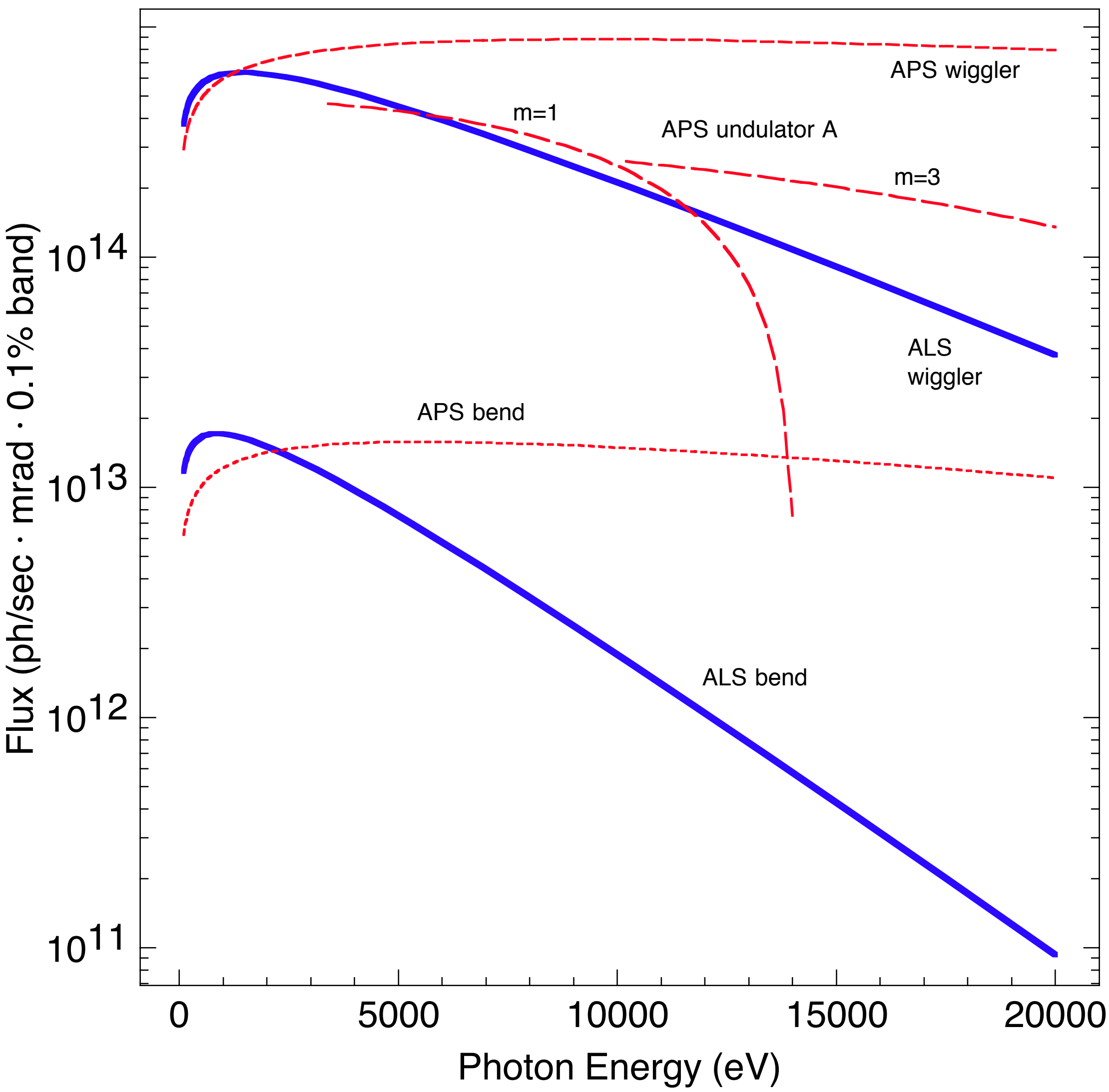

Fig. 1 Flux of ALS and APS sources

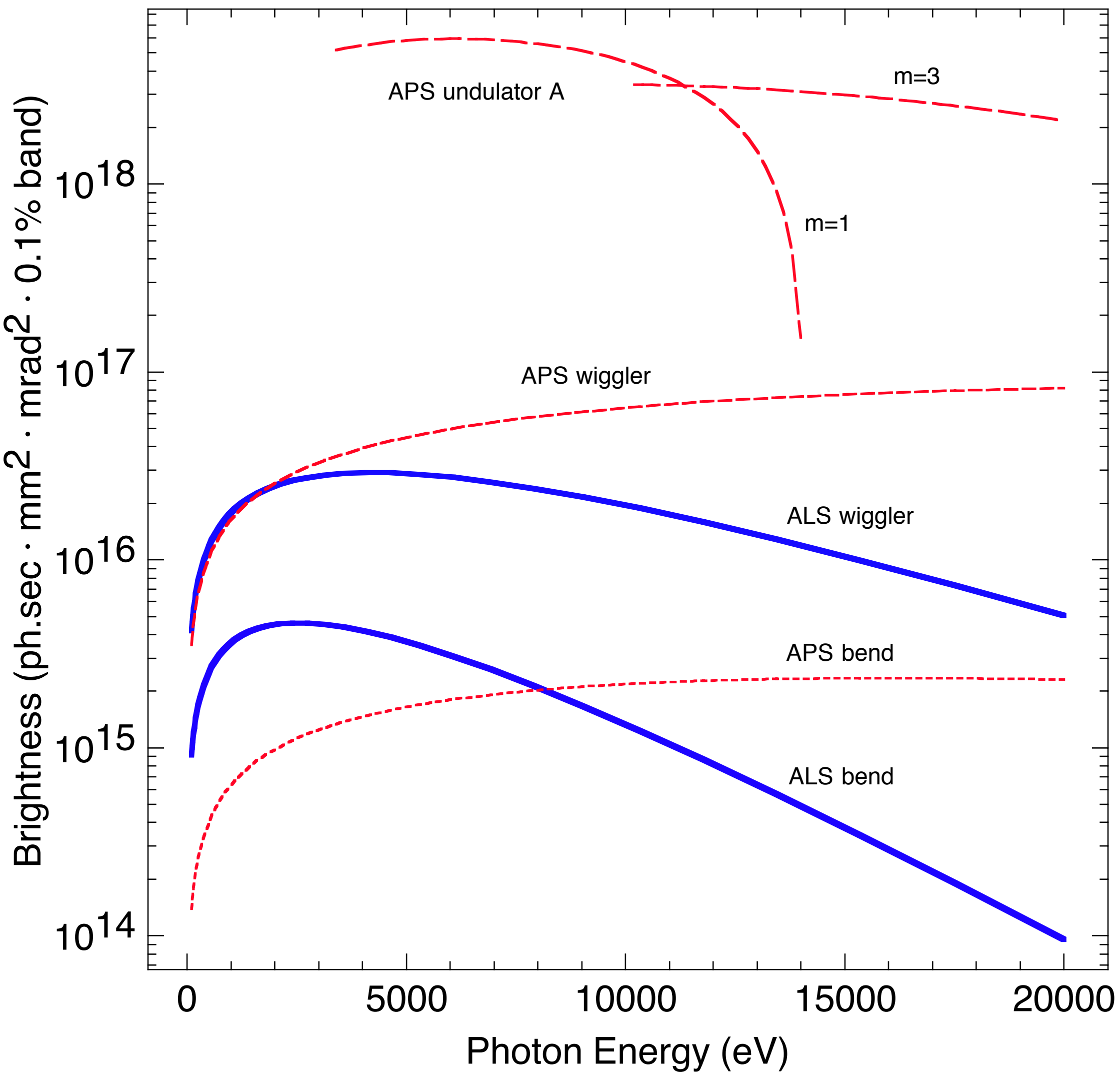

Fig. 2 Brightness of ALS and APS sources

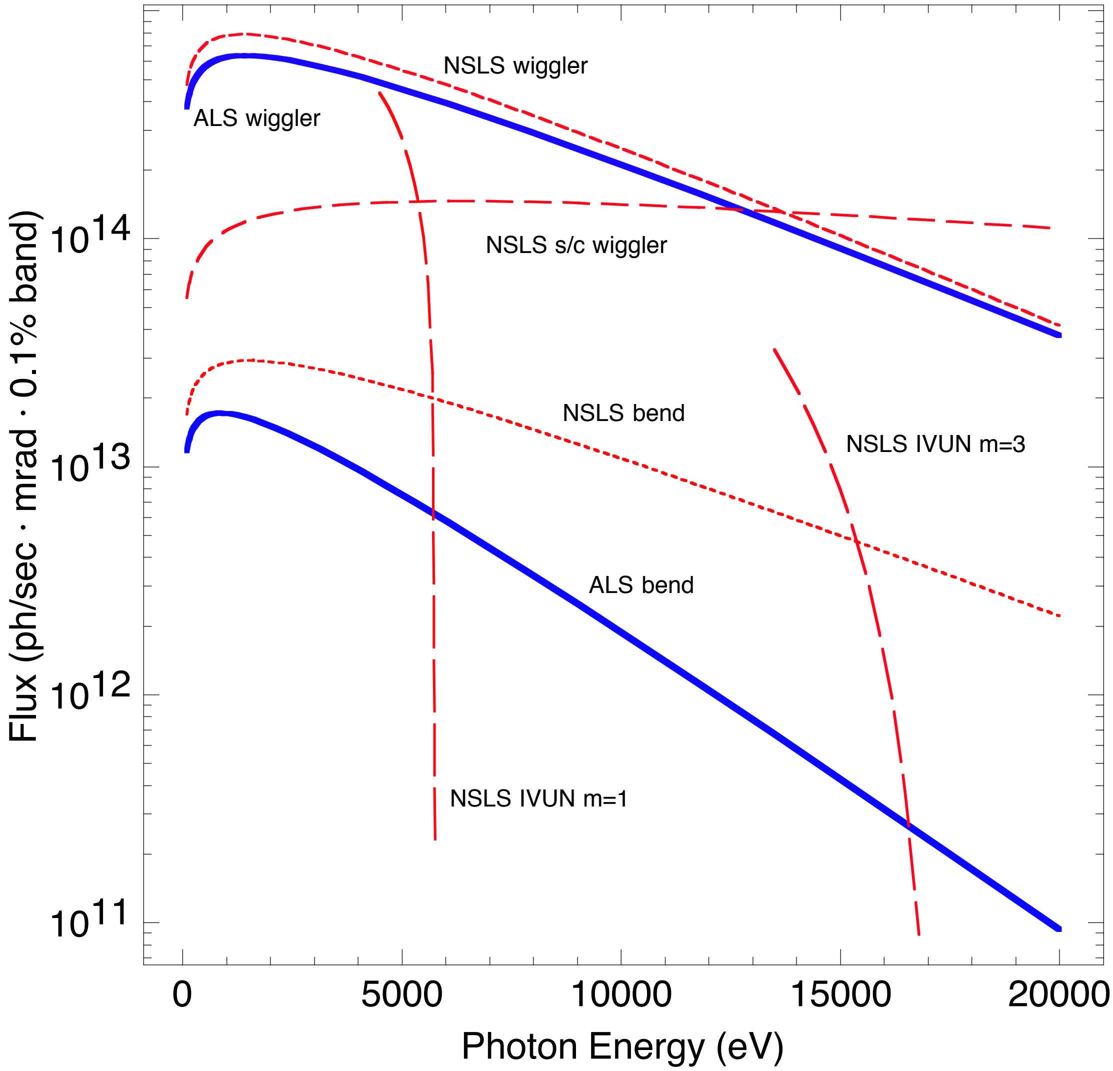

Fig. 3 Flux of ALS and NSLS sources

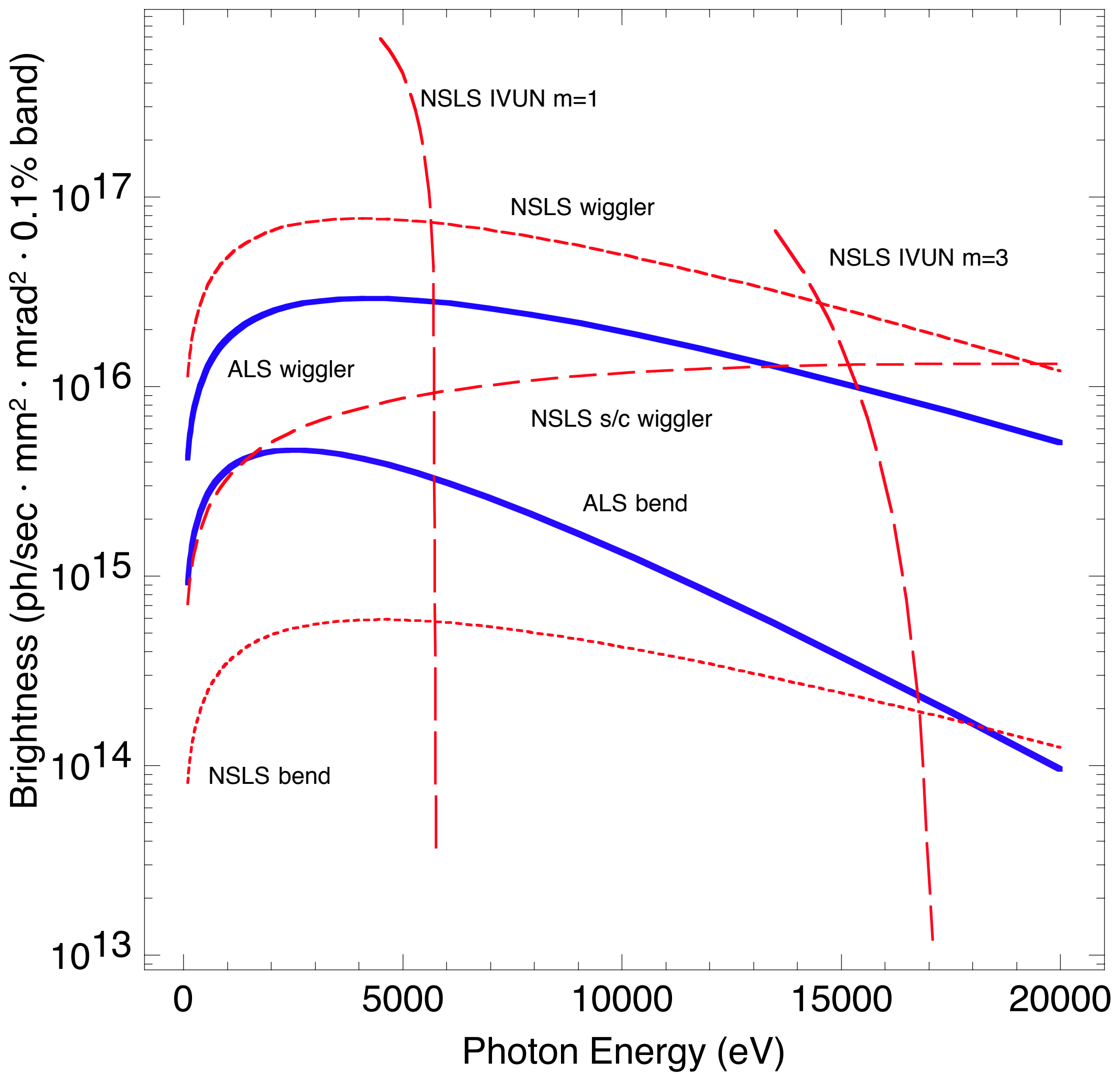

Fig. 4 Brightness of ALS and NSLS sources

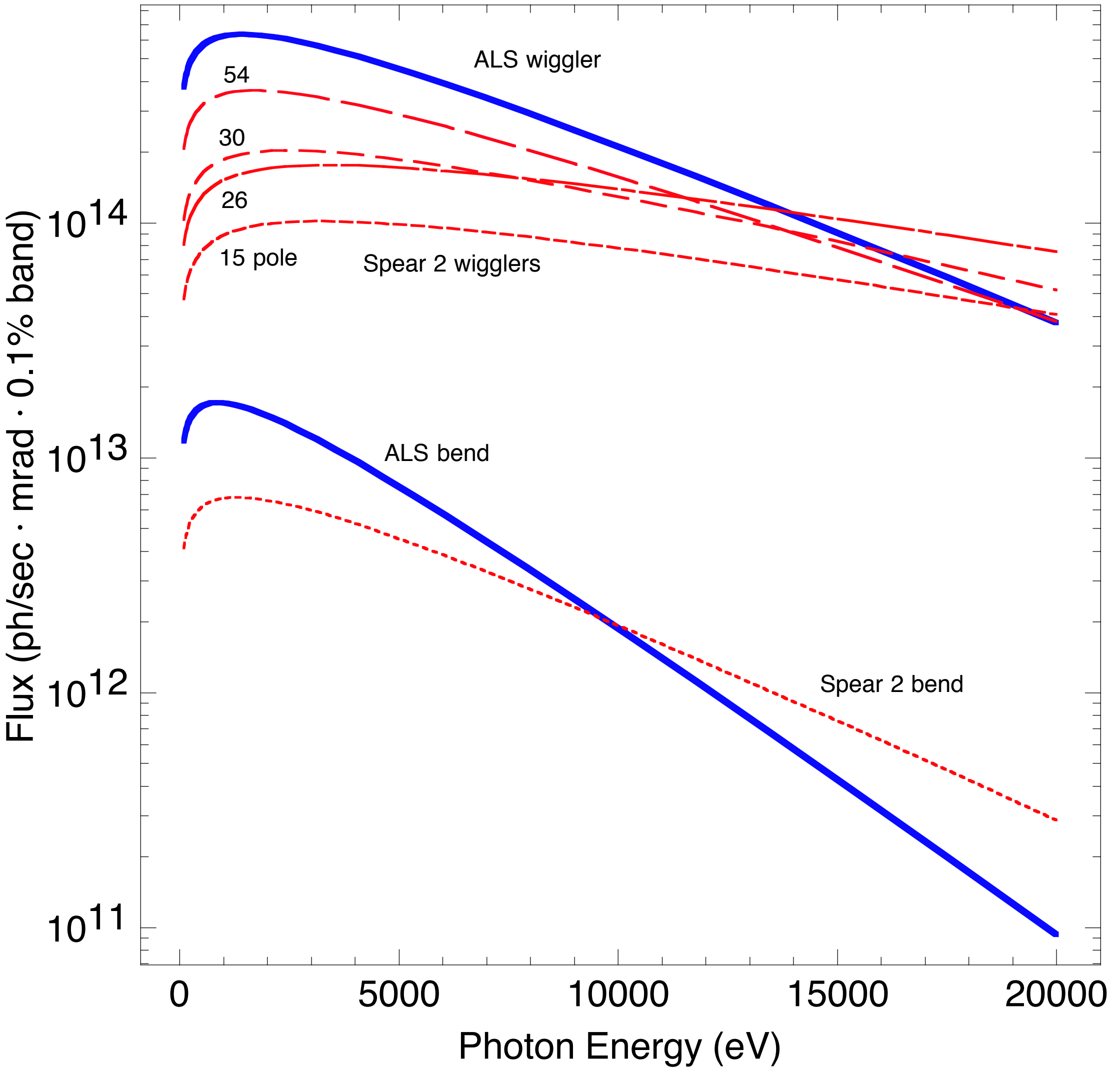

Fig. 5 Flux of ALS and SSRL sources

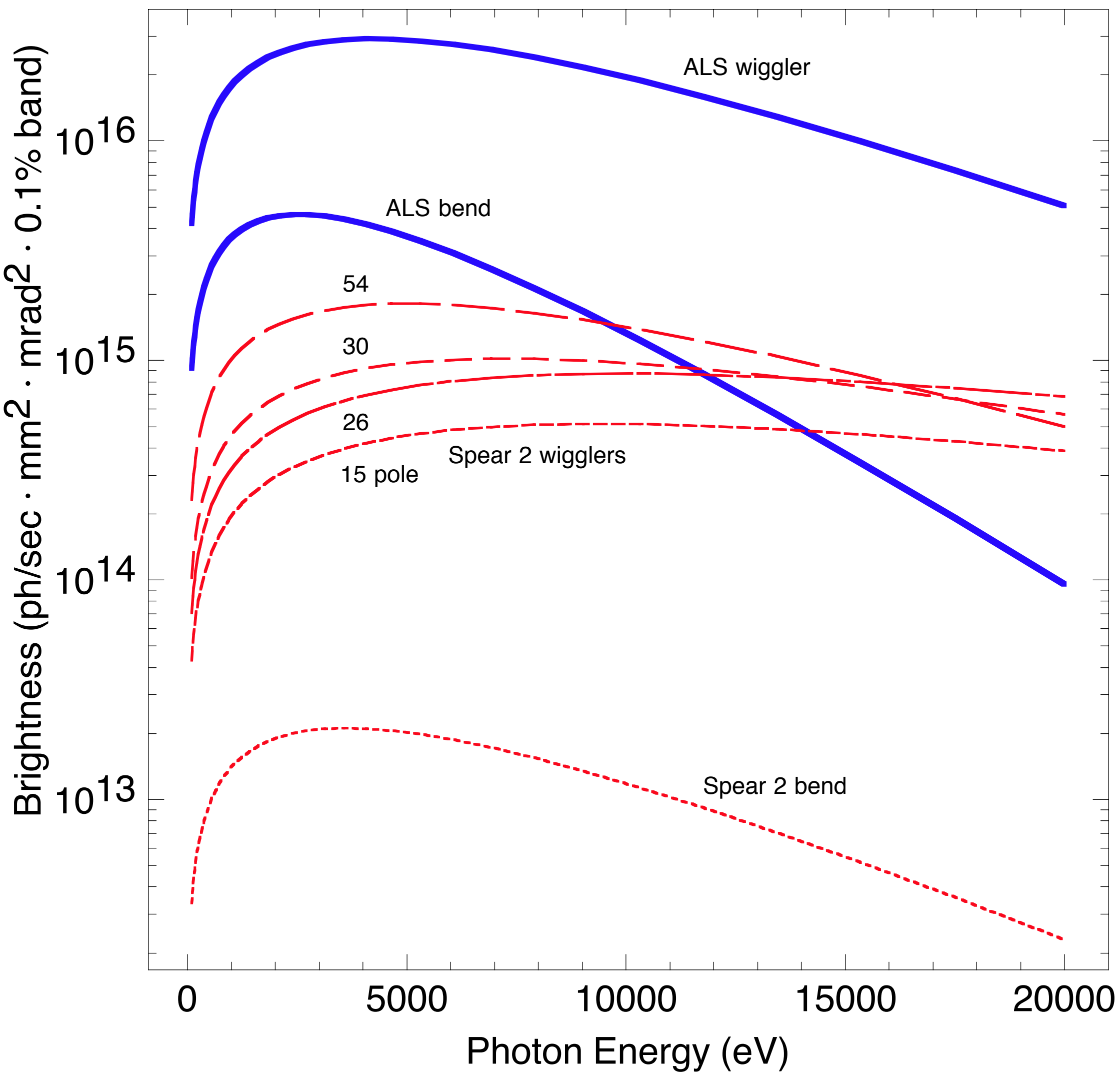

Fig. 6 Brightness of ALS and SSRL sources

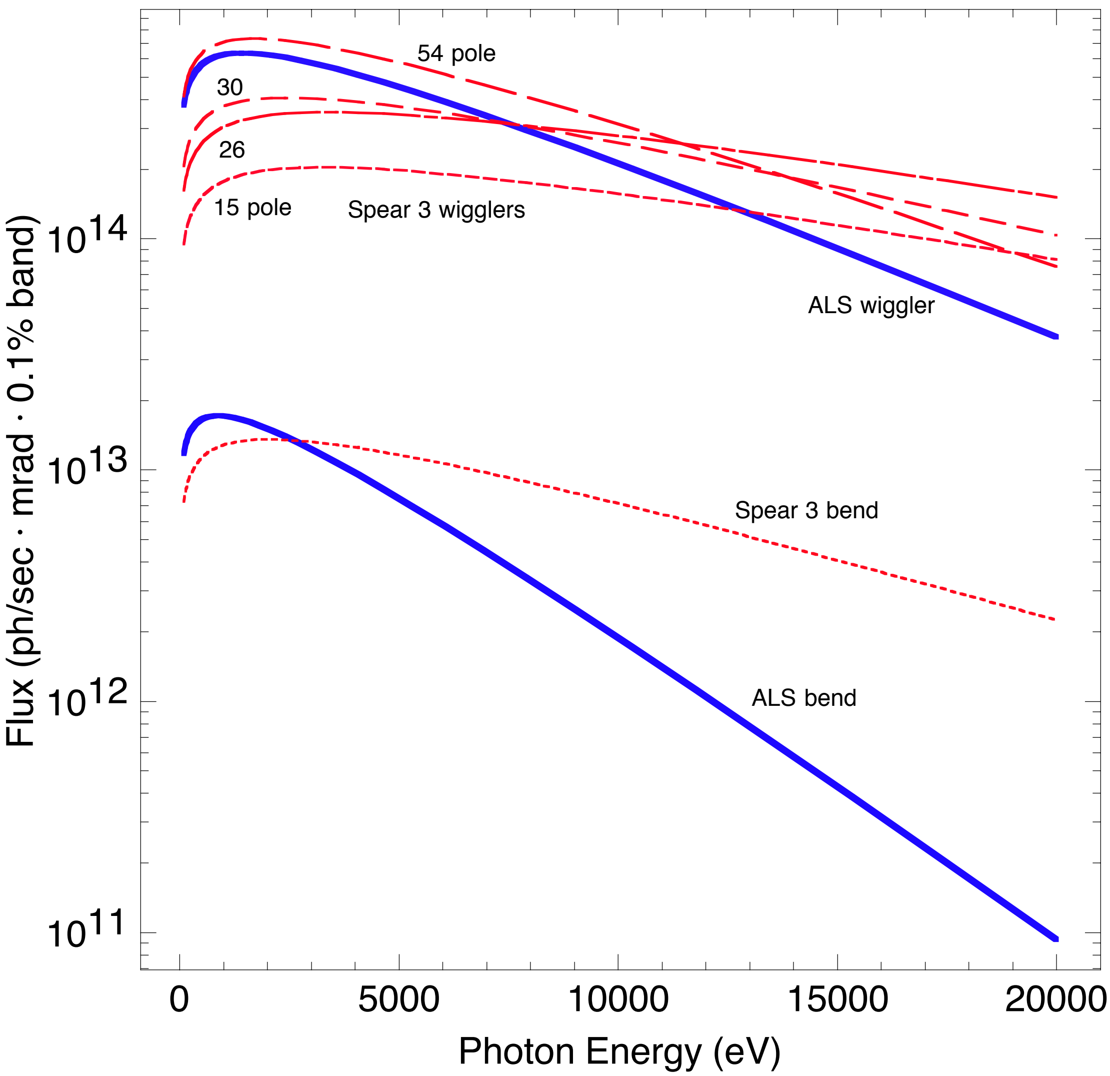

Fig. 7 Flux of ALS and SPEAR3 sources

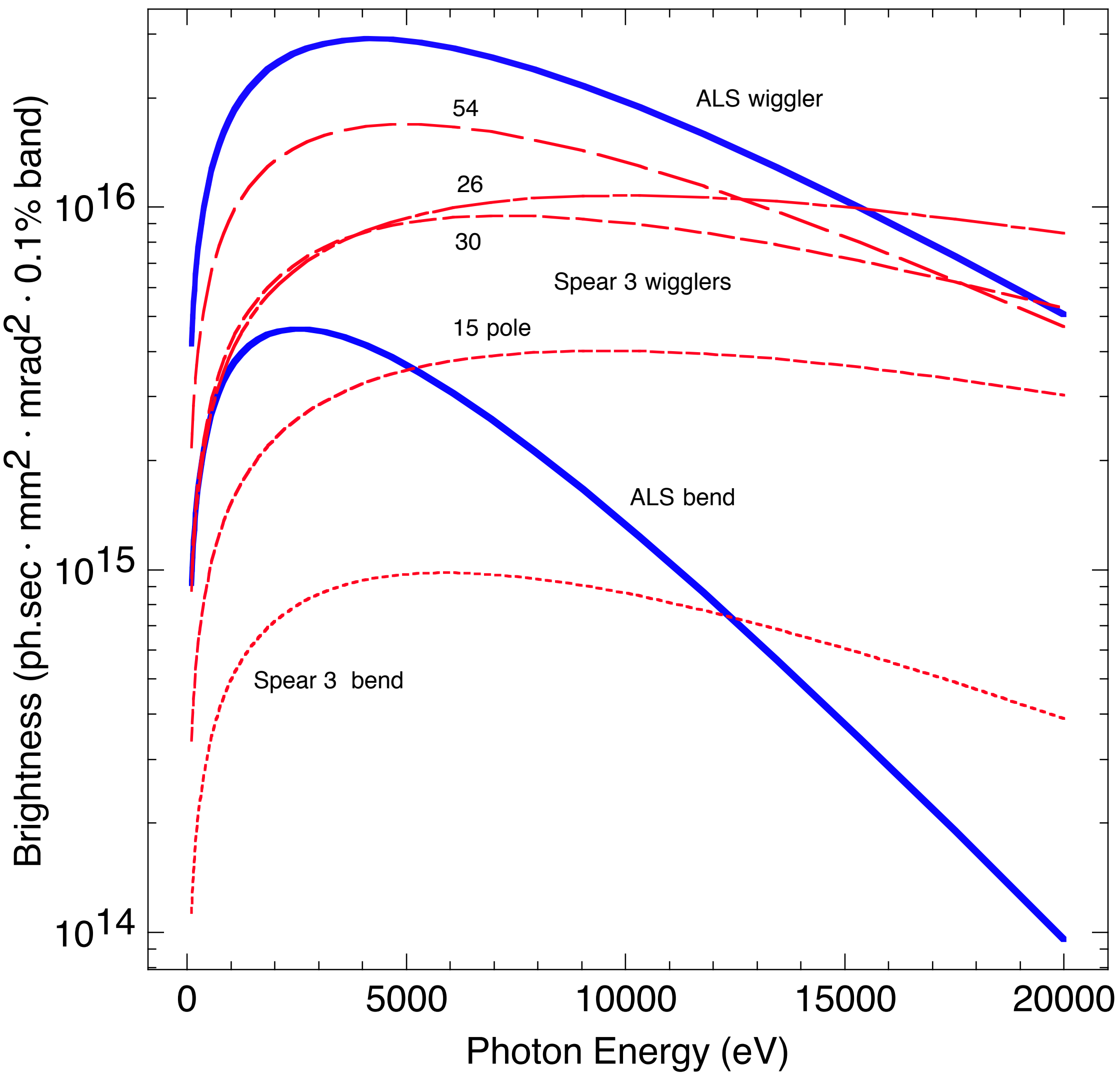

Fig. 8 Brightness of ALS and SPEAR3 sources

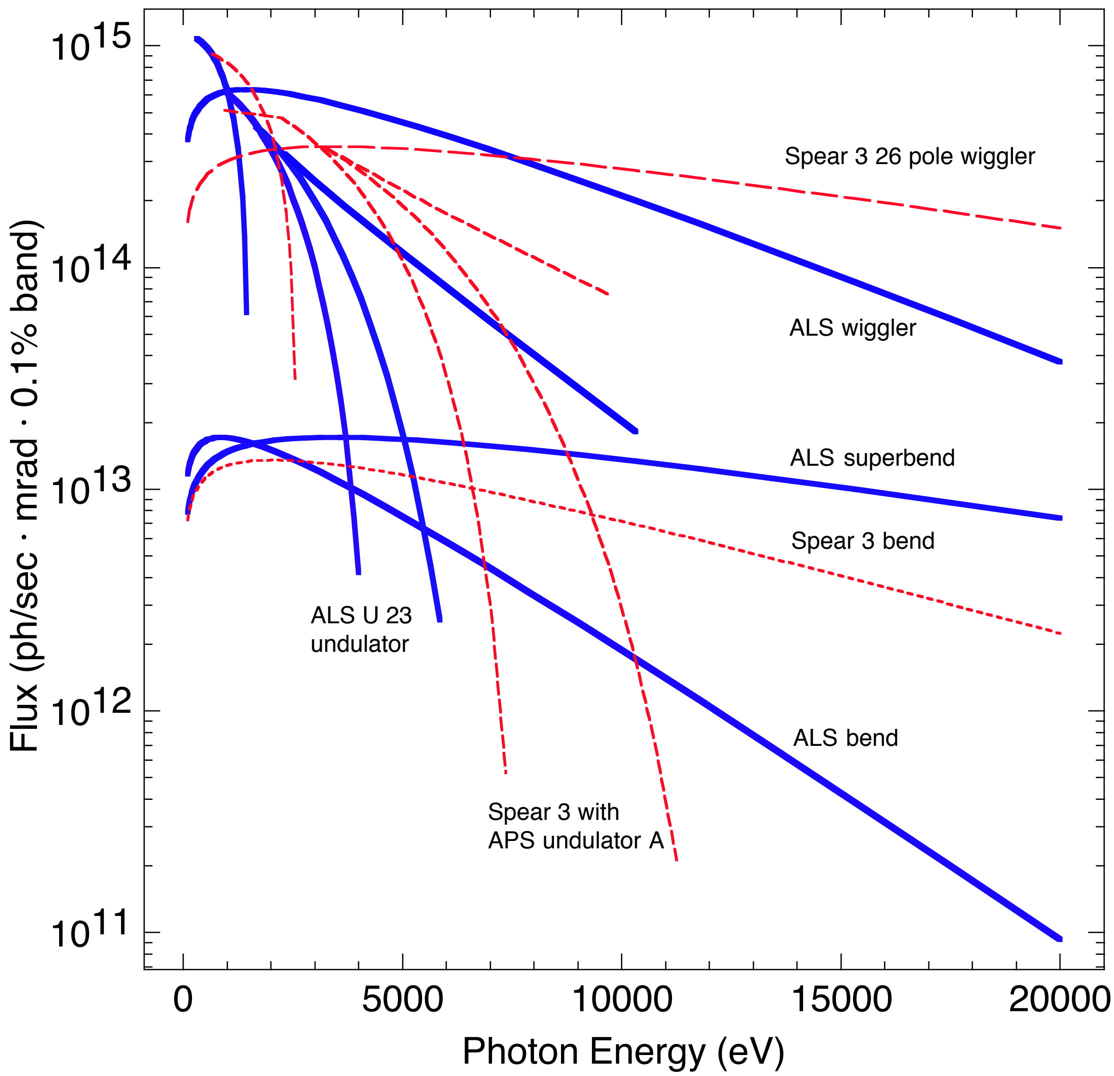

Fig. 9 Flux of ALS and SPEAR3 with additional sources

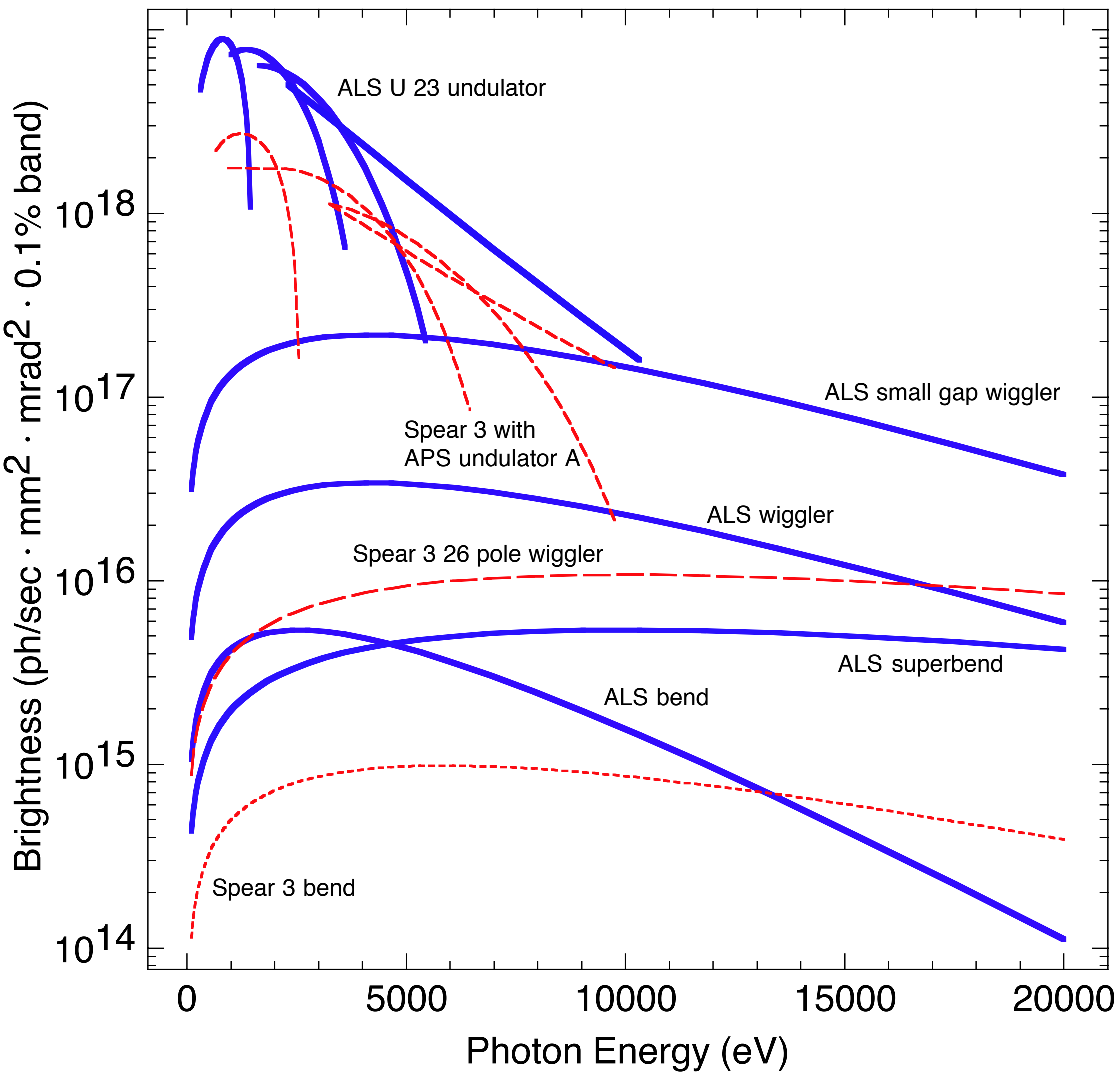

Fig. 10 Brightness of ALS and SPEAR3 with additional sources

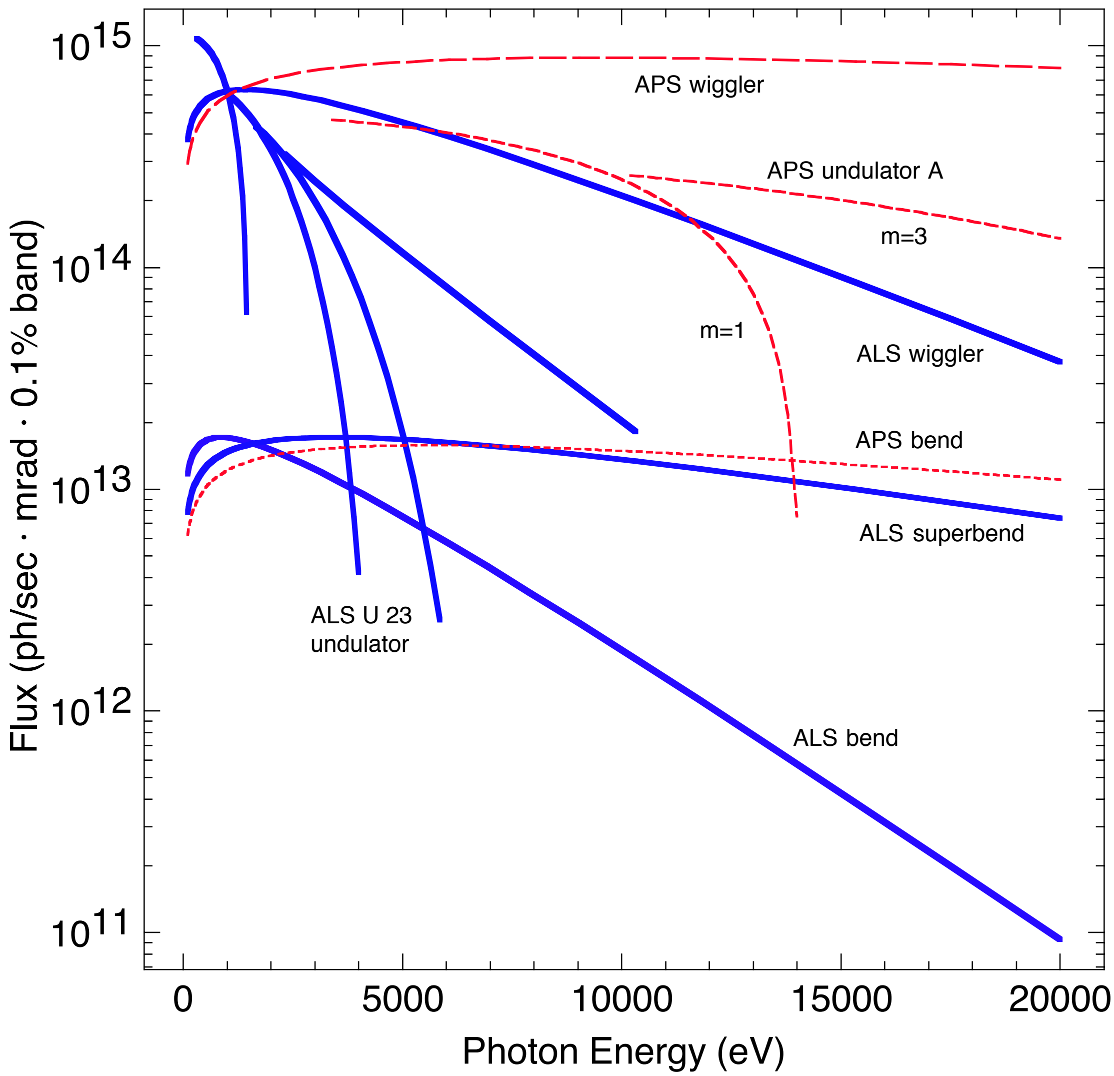

Fig. 11 Flux of the ALS with superbends, a small gap undulator and a small gap wiggler and of the APS

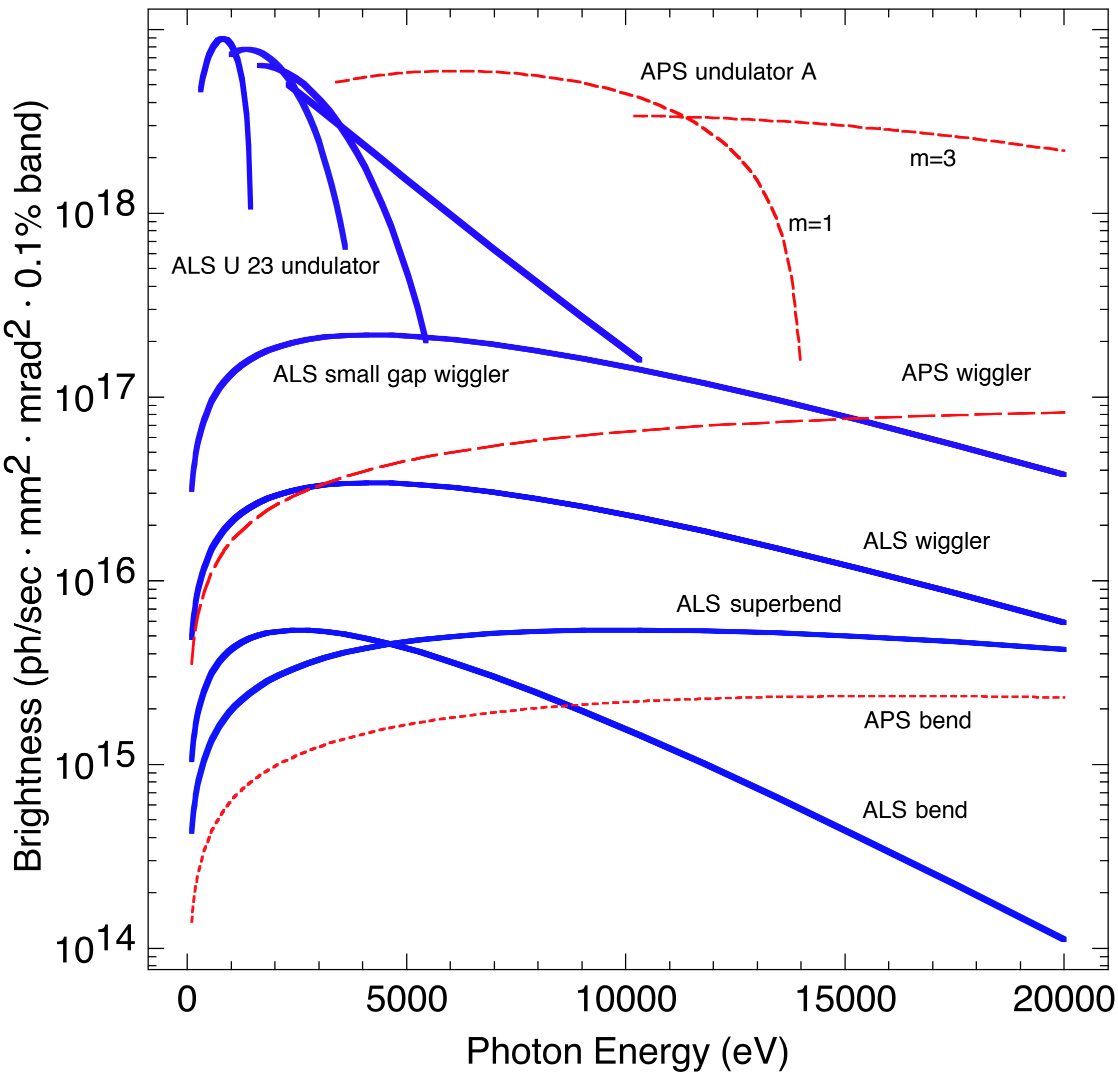

Fig. 12 Brightness of the ALS with superbends, a small gap undulator and a small gap wiggler and of the APS